INVESTMENT CASTING METHOD AND CORES AND DIES USED THEREIN

BACKGROUND OF THE INVENTION

[0001] This invention relates to investment casting of complex articles. More particularly, this invention relates to the manufacture and use of integral, sacrificial cores for investment casting complex articles.

[0002] In a gas turbine engine, compressed air is mixed with fuel in a combustor and ignited, generating a flow of hot combustion gases through one or more turbine stages that extract energy from the gas, producing output power. Each turbine stage includes a stator nozzle having vanes that direct the combustion gases against a corresponding row of turbine blades extending radially outwardly from a supporting rotor disk. The vanes and blades include airfoils having a generally concave "pressure" side and a generally convex "suction" side, both sides extending axially between leading and trailing edges over which the combustion gases flow during operation. The vanes and blades are subject to substantial heat load, and, because the efficiency of a gas turbine engine is a function of gas temperature, the continuous demand for efficiency translates to a demand for airfoils that are capable of withstanding higher temperatures for longer service times.

[0003] Gas turbine airfoils on such components as vanes and blades are usually made of superalloys and are often cooled by means of internal cooling chambers. The internal air-cooling of turbine airfoils is often accomplished via a complex cooling scheme in which cooling air flows through channels within the airfoil ("internal air-cooling channels") and is then discharged through a configuration of cooling holes at the airfoil surface. Convection cooling occurs within the airfoil from heat transfer to the cooling air as it flows through the cooling channels.

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[0004] Turbine components such as blades and vanes are often fabricated by investment casting, a technique used to manufacture complex, high-precision parts. Investment casting is performed by first forming a wax pattern of the part to be cast, then encapsulating the wax pattern with a ceramic shell. The encapsulated shell is then heated to cure the ceramic and melt the wax, leaving a ceramic mold having a cavity in the precise shape of the part to be cast. Molten metal is then poured into the ceramic shell and solidified, and the ceramic is removed by a combination of mechanical and chemical means to produce a final metal casting suitable for various finishing operations. Using this method to produce parts with internal channels is complicated by the need for the ceramic shell to include internal mold cores that define the channels. These ceramic mold cores are often formed by injection molding, and as the desired cooling channel configuration for an airfoil component becomes more complicated, the ability to form the required mold cores becomes more difficult due to the demands placed upon the injection molding process to completely fill convoluted, narrow passageways in the injection molding die.

[0005] Recently, turbine components having multiple airfoil walls have been designed to achieve still further enhanced cooling efficiency. Examples of these designs include those set forth in U.S Patents 5,484,258; 5,660,524; 6,126,396; and 6,174,133. One drawback to such complicated designs is the difficulty and expense involved in investment casting airfoils with multiple walls, because the complexity of the cooling circuits is such that the required mold cores cannot be formed in a single injection into a conventional die. Instead, multiple cores are generally formed by separate injections, followed by assembling the multiple cores into a composite core. This assembly step is time-consuming and introduces a source for variation in the final dimensions of the cast part, particularly in the thickness dimension of the various walls. Therefore, an alternative method for forming casting cores that allows the formation of an integral core would be advantageous, especially in the fabrication of components having multiple walls. Furthermore, alternative methods for forming articles having multiple walls, where the method is less time-consuming and repeatable than current methods, would also be advantageous.

BRIEF DESCRIPTION

[0006] These and other needs are addressed by embodiments of the present invention.

[0007] One embodiment is a method for making a component. The method comprises providing a single-piece sacrificial die, the die comprising at least one internal cavity; introducing a ceramic slurry into the at least one cavity of the die, the slurry comprising a ceramic and a carrier fluid; curing the slurry to form a ceramic casting core; removing the sacrificial die by exposing the die to an environment adapted to destroy the die while leaving the ceramic casting core intact; and performing an investment casting process using the ceramic casting core as part of a mold-core assembly to form the component.

[0008] A second embodiment is a method for making a casting core. The method comprises manufacturing a single-piece sacrificial die using an additive layer manufacturing method, the die comprising an internal cavity; introducing a ceramic slurry into the cavity of the die, the slurry comprising a ceramic and a carrier fluid; curing the slurry to form a ceramic casting core; and removing the sacrificial die by exposing the die to an environment adapted to destroy the die while leaving the ceramic casting core intact. Embodiments of the present invention further include the casting core made by the above method.

[0009] A further embodiment is a die for making a casting core. The die comprises a single- piece structure comprising at least one cavity, and this structure comprises a material capable of being selectively removed from a ceramic casting core when the ceramic casting core is disposed in the at least one cavity.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0011] Figure 1 is a cross sectional view of an exemplary component which is capable of being manufactured by embodiments of the present invention.

DETAILED DESCRIPTION

[0012] Referring to Figure 1, a component 10 is made according to method embodiments of the present invention. In particular embodiments, component 10 comprises an external wall 20 and at least one internal wall 30 disposed in a spaced-apart relationship with external wall 20. Such components are referred to herein as "multi-wall components." In the method of the present invention, a single-piece sacrificial die is provided. Conventional dies are generally constructed to be used multiple times and are usually two-piece designs, but the complicated geometry of the cooling circuits used in multi-wall components 10 makes the use of dies having two pieces very difficult and often impossible, requiring in conventional methods additional time and effort for multiple injected cores to be formed and assembled into a composite core. The single-piece sacrificial die comprises at least one internal cavity. As used hereinafter, the singular term "cavity" will be used to refer to the at least one cavity within the die, but it should be understood that the use of the singular term "cavity" also refers to the case where more than one cavity is contained within the die. The shape of the cavity corresponds to the shape desired for the complex mold core to be used in casting the component 10.

[0013] According to certain embodiments of the present invention, the single-piece sacrificial die is provided through the use of one or more additive layer manufacturing processes. The die, in particular embodiments, comprises at least one sacrificial material selected from the group consisting of an epoxy, a silicone, and a metal. In an additive layer process, a product is "assembled" by producing and sequentially stacking thin cross-sectional layers one on top of the other, generally starting at one end of the product and working towards the opposite end. Such methods often use a three-dimensional computer-aided drafting ("CAD") file of the product to guide an automated assembly process, where the CAD model file is digitally partitioned into "slices" corresponding to the actual layers being generated and stacked, and these "slices" guide automated assembling equipment such as, for example, robotic arms. The nature of the additive layer process allows single-piece articles of high internal complexity, such as, for example, closed internal chambers and tortuous internal channels, to be easily assembled in one continuous operation. Therefore, additive layer manufacturing processes are well suited to the creation of a complicated single-piece die as used in embodiments of the present invention, because such a die will often be designed to have a complicated internal structure that corresponds to the complex internal cooling circuits of the component desired to be cast.

[0014] Stereolithography (SLA) is an example of an additive layer process that is suitable for use in embodiments of the present invention. During SLA, a robotic arm holds a laser, and the arm precisely guides the motion of the laser along a motion path described by the "sliced" CAD file. The laser directs highly focused radiation upon a curable material medium, often a liquid resin, which is instantly solidified ("cured") upon exposure to the laser, thereby creating a single, precisely rendered cross-sectional layer of the product that corresponds with the "slice" of the partitioned CAD file. This procedure is repeated for all subsequent layers, with each layer being bonded to the previous one by the action of the solidifying material medium. The finished product is a three-dimensional product rendered in cured material with all dimensions in accordance with the CAD file.

[0015] A long list of other additive layer manufacturing processes are available in the art and are suitable for providing the single-piece sacrificial die in embodiments of the present invention, including, but not limited to, micro-pen deposition, where liquid media is dispensed with high precision at the pen tip and then cured; selective laser sintering, where a laser is used to sinter a powder media in precisely controlled locations; and laser wire deposition, where a wire feedstock is melted by a laser and then deposited and solidified in precise locations to build the product. Those skilled in the art will appreciate that a variety of curable material media may be applied, including liquid resins, as described above, and solid media in various forms such as powders, wires, and sheets. Silicone-based and organic-based resins are the most common examples of curable material media used in these methods, although in some methods the media comprises at least one metal, often mixed with some type of resin.

[0016] A ceramic slurry is introduced into the cavity (or cavities) of the sacrificial die. The slurry comprises a ceramic powder and a liquid phase, or "carrier fluid." The slurry contains sufficient liquid phase to provide a viscosity that is usually less than about 10,000 Pascal-seconds, that is, a viscosity that renders the slurry suitable for introduction into, and proper filling of, the die cavity. Suitable ceramics for use in the slurry include, but are not limited to, alumina, yttria, ceria, zirconia, magnesia, and calcia. In many cases the introduction of the ceramic slurry into the cavity of the die is done with the slurry under pressure to ensure the slurry completely fills the cavity. Injection molding is an example of a suitable method for introducing the slurry into the die cavity, because the quantity and pressure of the slurry may be precisely controlled as the slurry fills the die cavity.

[0017] After the slurry has completely filled the die cavity, the slurry is cured to form a ceramic casting core. Curing the slurry is done by removing the liquid phase, and in certain embodiments this is done by heating the slurry to evaporate the carrier fluid, leaving only the ceramic phase contained within the die cavity.

[0018] The die is then removed from around the ceramic casting core contained in the die cavity. Because the die is one piece, it cannot be removed without being destroyed, hence the die is sacrificial in the method of the present invention. The die is exposed to an environment, such as, for example, mechanical stress, temperature, chemicals, and combinations thereof, that is adapted to destroy the die while leaving the ceramic casting core intact. In certain embodiments, removing the die comprises heating the die. In these embodiments, the die is heated to a temperature that causes the die to decompose or burn away, while the ceramic core remains unaffected. In some embodiments, the die is removed by dissolving it in a solvent. Those skilled in the art will appreciate that the choice of solvent depends upon the composition of the die. In some embodiments, the die is chemically removed, such as, for example, by reacting the die material with an acid, base, or other compound or mixture that chemically reacts with and removes the die material. Regardless of how the die is removed, the environment is chosen to selectively remove the die material while leaving the ceramic material intact.

[0019] After removing the die, a freestanding, one-piece ceramic core remains, suitable for use in investment casting multi-wall component 10. The ceramic core may be of a much higher complexity than is possible to achieve in a one-piece core made by conventional techniques, due to the use of the single-piece sacrificial die and, in certain embodiments, the use of the additive layer manufacturing process in making the die. The core is often fired at a temperature in the range from about 870°C to about 1100°C to provide the core with sufficient strength to survive subsequent operations. An investment casting process is performed in accordance with industry practice, using the ceramic core made above as part of a mold-core assembly to form component 10. In general, the core and appropriate ancillary material known to those skilled in the art (such as positioning and support pins, sprues, gates, etc.) are disposed in a mold appropriately shaped in accordance with the design of the component to be cast. Wax is injected into the mold and solidified to form a wax model, and this wax model with embedded core is repeatedly dipped in ceramic slurry to form a ceramic shell mold around the wax pattern. After removing

the wax, all that remains is the ceramic core disposed in and attached to the ceramic shell mold, thereby forming the mold-core assembly referred to above. After casting the component by solidifying molten metal in the mold-core assembly, the ceramic mold is removed by chemical or mechanical means and the core is "leached" out of the component by a chemical removal agent.

[0020] The use of the single-piece sacrificial die to make a one-piece ceramic core, particularly in embodiments employing SLA or other additive layer manufacturing process to make the sacrificial die, allows for repeatable production of high quality castings without the time-consuming steps of forming multiple core components and joining them together into a composite core prior to wax injection.

[0021] The method described above is suitable for forming any investment cast article. In some embodiments, the component 10 being made is a component of a turbine assembly, such as, for example, a turbine blade or a vane, including multi-wall blades or vanes. In particular embodiments, component 10 comprises at least one internal air-cooling passage 40. Because the complexity of internal passage geometry is easily accommodated by the additive layer manufacturing process used to fashion the core die, adding additional features to the component is readily accomplished with little added expense. For instance, in certain embodiments, the at least one cooling passage 40 of component 10 comprises turbulators (not shown) to enhance heat transfer within cooling passage 40.

[0022] The advantages offered by the method of the present invention are most apparent when the method is employed to make such complicated, multi-wall components, due to the savings in both time and cost attributable to the use of the single-piece sacrificial die as described above. For example, one embodiment of the present invention is a method for making a component for a turbine assembly. The component is a multi-wall component, and therefore it comprises an external wall and at least one internal wall disposed in a spaced-apart relationship with the external wall, and further comprises at least one cooling passage disposed between the external wall and the internal wall. The method comprises using a stereolithography process

to provide a single-piece sacrificial die having at least one internal cavity; introducing a ceramic slurry as described previously into the at least one cavity of the die; curing the slurry to form a ceramic casting core; removing the sacrificial die by exposing the die to an environment adapted to destroy the die while leaving the ceramic casting core intact; and performing an investment casting process using the ceramic casting core as part of a mold-core assembly to form the component.

[0023] Other embodiments of the present invention include a method for making a casting core, and the casting core made by the method. In this method a single-piece sacrificial die is manufactured using an additive layer manufacturing method as described above. The die comprises at least one internal cavity, into which a ceramic slurry is introduced and then cured. After curing, the die is removed as previously described. The various alternatives for materials and processes described for previous embodiments are equally applicable in this embodiment.

[0024] In particular embodiments the core is configured to form internal passages, such as, for example, air-cooling passages, in an investment cast article. That is, the core is designed to correspond with the geometry of these passages, so that when the investment casting process is carried out, the ceramic core will be leached away from the internal surfaces of the component, leaving behind the desired configuration of internal passages. In certain embodiments, the investment cast article for which the core is configured is a component of a turbine assembly, such as, for instance, a multi-wall component.

[0025] A further embodiment of the present invention is a die for making a casting core. The die comprises a single piece structure having at least one cavity, and is made of a material capable of being selectively removed from a ceramic casting core when such a core is disposed in the cavity of the die. That is, the die material can be destroyed by an environment while a ceramic casting core disposed within the cavity of the die remains intact, as described previously. In certain embodiments the structure of the die comprises a structure assembled in an additive layer manufacturing process, such as the SLA process described previously.

[0026] While various embodiments are described herein, it will be appreciated from the specification that various combinations of elements, variations, equivalents, or improvements therein may be made by those skilled in the art, and are still within the scope of the invention as defined in the appended claims.